EN200

LAB #10

HULL RESISTANCE and EFFECTIVE HORSEPOWER

Instructions

1. This lab is conducted in the Hydro Lab on the lab deck of Rickover Hall.

2. You will need to bring this lab handout and your EN200 Chapter 7 notes to the lab period. You will also need drawing equipment to construct graphs.

3. This lab is to be performed individually, however, you are encouraged to ask questions and discuss the content of the lab with other students, however, the submitted work must be your own.

4. Prior to the scheduled lab period, you should read through this lab in its entirety. This will help you prepare for the work to be accomplished and give you a feel for the material to be covered.

5. For full credit, all work must be shown. This means that you must show generalized equations, numerical substitution, units, and final results. Engineering is communication. To be an effective communicator, other people must be able to follow and understand your work.

Student Information:

Name: ___________________________

Section: __________

Date: ____________

Aim:

- Reinforce the student's understanding of the components of hull resistance and effective horsepower.
- Demonstrate how wave making resistance affects total hull resistance.
- Determine the full-scale effective horsepower curve of a YP using model resistance data.
- Observe the effect that changing a ship's draft and displacement has on hull resistance.
- Observe the performance (resistance and seakeeping) of a YP hull in various wave conditions.
- Using fuel consumption data, determine how speed affects a ship's operational range.

Part 1: Information

Apparatus

1. The apparatus for this experiment consists of a scale model of a YP hull attached to the towing carriage in the 120 ft towing tank. The model and carriage are configured to record velocity and model resistance for each run down the tank.

2. The following model and ship data is provided:

Model Data	Full-Scale YP Data
Length between perpendiculars (L_M) = 5 ft	Length between perpendiculars (L_S) = 101.65 ft
Scale Factor (λ) = 20.330	
Fresh water at 59°F	Salt water at 59°F

Background

1. Ship resistance is a function of many factors. Some factors affecting resistance include ship speed, hull form and size, displacement, hull fouling, water temperature, waves, current, and wind.

2. In the design of a ship, many towing tank tests of a model geometrically similar to the full-scale ship are performed to determine the ship's horsepower requirements and performance characteristics. Tests are done on several hull designs in order to select the "best" hull to be constructed. A carefully planned and executed series of model tests, although somewhat expensive, is extremely beneficial and cost efficient in selecting the final design of a ship's hull. Data collected on a model can easily be scaled up to predict the full-scale ship's performance.

3. Instead of testing a potential design for a ship, this lab will use an established hull design, the USNA YP, and will concentrate on the effect of an increase in ship displacement on the power required to propel the ship through the water.

4. Throughout the life of a ship its displacement will change, whether through fuel and water consumption, or because of equipment additions. History has shown that a ship's displacement (especially warships) will increase 10-15% over the life of a ship. For instance, the FFG-7 class was initially designed for a displacement of 3,700 LT. The class now has an operational displacement of approximately 4,100 LT, an increase of 10%.

5. This lab will look at and compare the effective horsepower of the YP hull at an initial design displacement of 139 LT with its current displacement of about 172 LT.

Components of Hull Resistance

1. In the laboratory, the two most important components of hull resistance are viscous and wave making resistance. Mathematically, this is written as:

$$R_T = R_V + R_W$$

where: R_T = total hull resistance
R_V = viscous resistance
R_W = wave making resistance

2. Describe each of the components of resistance included in the total hull resistance found in the laboratory:

Viscous Resistance: ____

____

Wave Making: ____

____

3. Figure 1 on the following page is a graph showing the components of resistance for a YP hull. Note how the wave making component of resistance increases as speed increases. At speeds of 4, 8, and 14 knots, what percentage of the total resistance can be attributed to wave making?

4 knots: _______ 8 knots: _______ 14 knots: ________

4. The graph of total hull resistance shows a slight "hump" at a speed of 6 knots. What factor has caused this hump to occur?

____

____

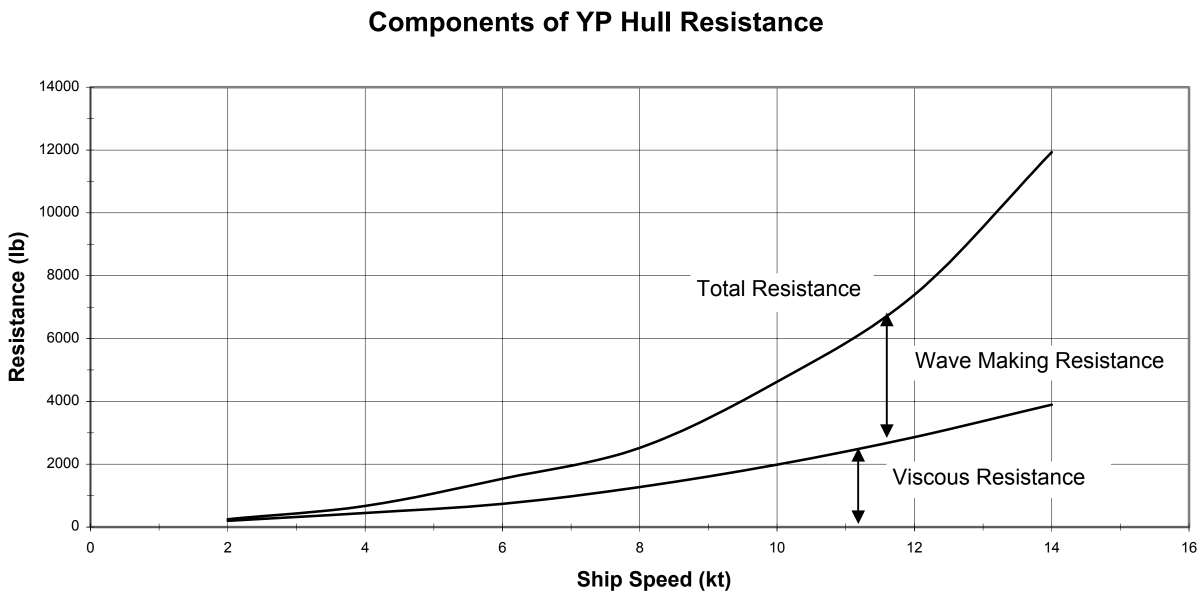

Figure 1: Components of YP total hull resistance

Effective Horsepower

Baseline Data (Δ_S = 139 LT)

1. Table 1 below contains bare hull EHP data for a YP at a displacement of 139 LT. Data was collected from a series of model tests and then scaled up to full-scale EHP predictions. Carefully plot this data on the blank graph located at the back of this lab.

Table 1: YP EHP Data at Δ_S=139 LT

Ship Speed, V_S (kts)	Effective Horsepower, EHP (HP)
2	2
4	8
6	28
8	62
10	142
12	272
14	512

Resistance at Δ_S = 172 LT

1. The model will now be towed in the tank at scale speeds corresponding to full-scale ship speeds (V_S) of 4, 7, 12, and 14 knots.

   a. Using the following equation, calculate the speed at which the model must be towed (V_M in ft/s) in order to correspond to full-scale speeds of 4, 7, 12, and 14 knots. Enter your results in Table 2 on the following page.

$$\frac{V_S\,(\frac{ft}{\sec})}{V_M\,(\frac{ft}{\sec})} = \frac{\sqrt{L_S\,(ft)}}{\sqrt{L_M\,(ft)}}$$

   Note: 1 kt = 1.688 ft/sec

   b. Why is the model being towed at speeds using the above equation (Froude's Law of Corresponding Speeds)?

   ____

   ____

   c. Why does the model have a row of studs running vertically near its bow?

   ____

   d. As the model is being towed, carefully observe the wave pattern (transverse and divergent waves) created by the model as it moves down the tank. Note how the size of the waves increases, and the wavelength increases as the model's speed increases. Sketch the transverse and divergent wave patterns for speeds of 4 and 14 knots on the diagrams in Figure 2 on the following page.

   e. Record the total hull resistance of the model (R_{TM}) in Table 2 on the following page.

   f. A very good approximation of the total hull resistance for a ship is to multiply the total hull resistance of the model by the cube of the scale factor. Using the relationships below, complete the data in Table 2.

$$R_{TS} \cong R_{TM}\lambda^3 \qquad\qquad EHP = \frac{R_{TS}\,(lb)V_S\,(\frac{ft}{\sec})}{550(\frac{ft-lb}{\sec-HP})}$$

   g. When conducting model tests, is it better to use a larger or smaller model? Why?

   ____

   ____

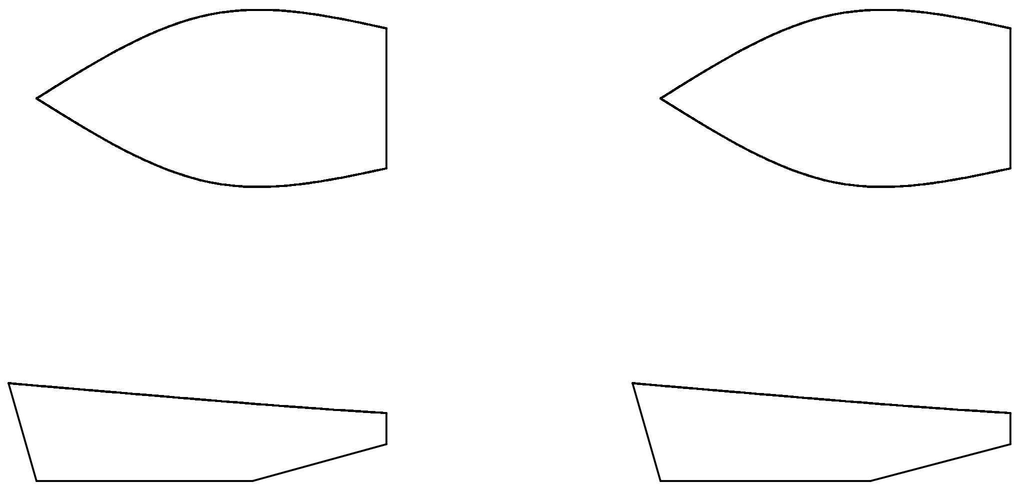

Figure 2: Diagram of YP wake patterns at speeds of 4 and 14 knots.

Table 2: YP Resistance and EHP Data at Δ_S = 172 LT					
V_S (kt)	**V_S (ft/s)**	**V_M (ft/s)**	**R_{TM} (lb)**	**R_{TS} (lb)**	**EHP (HP)**
4					
7					
12					
14					

Show your understanding of these calculations by showing your work for a ship speed of 12 knots in the space below.

2. Plot your EHP results for a displacement of 172 LT on the same plot as the EHP data for a displacement of 139 LT.

   a. What happened to the effective horsepower of the YP after increasing its displacement to 172 LT? Why?

   ____

   ____

   ____

   b. How does increasing speed affect the effective horsepower at a displacement of 172 LT? Specifically, what has happened to the horsepower requirement as speed increased from 4 to 7 knots, and from 12 to 14 knots?

   ____

   ____

   ____

   ____

   c. The YP's have a maximum speed of 13.25 knots. Based on your data, explain why this value may have been chosen.

   ____

   ____

   ____

   d. List three other types of resistance that were not accounted for in calm water model testing:

   1. ____________________
   2. ____________________
   3. ____________________

   e. How would operating in shallow water affect the YP's effective horsepower?

   ____

Added Resistance and Ship Hull Response in Regular Waves

1. To look at how ocean waves affect resistance over and above calm water resistance, the model will now be towed at a constant speed corresponding to a full-scale speed of 12 knots in three different regular wave patterns. The three regular wave patterns will have the following characteristics: 1) wave length twice the model's length, 2) wave length equal to the model's length, and 3) wave length one half the length of the model. Full-scale wave height is approximately 4.2 ft (sea state 3).

2. During these runs, carefully observe the motion of the model, especially in pitch and heave. You will see a different response in each wave pattern. Record the dominant motion (pitch or heave) observed during each run below in the Table 3.

Table 3: YP Motion in Regular Waves

Wave Pattern	V_S (kt)	Dominant Response Motion
$L_{wave} = 4*L_M$	12	
$L_{wave} = L_M$	12	
$L_{wave} = ½L_M$	12	

3. To illustrate the effect that waves have on resistance, the resistance data in Table 4 was obtained for the YP at a displacement of 139 LT. Using this data and the previous equations for resistance and EHP, calculate the YP's total hull resistance and EHP in waves for each speed and plot your results on your EHP graph. Use the space below the table for your calculations.

Table 4: Resistance and EHP of a YP in Waves (Δ_S = 139 LT)

V_S (kt)	V_S (ft/s)	R_{TM} (lb)	R_{TS} (lb)	EHP (HP)
10		0.78		
12		1.14		
14		1.70		

4. What effect has the presence of waves had on the effective horsepower of the YP? Why?

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5. How would wind and current affect a ship's resistance and the power required to move through the ocean?

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____

6. Which regular ocean wave pattern produced the largest amount of pitching motion?

____

7. Which regular ocean wave pattern produced the largest amount of heave motion?

____

8. Based on your observations of ship motion in the lab, list and describe 3 additional factors, in addition to wavelength, that would affect the motion of a ship in waves.

   a.

   b.

   c.

Shaft Horsepower and Fuel Consumption

1. Once a ship's effective horsepower has been determined through model testing, the shaft horsepower required to drive the ship must be determined, since it is shaft horsepower that is purchased.

2. In the space below, sketch a diagram of a ship's drive train that shows the distinction between BHP, SHP, DHP, THP, and EHP. Clearly label each component of the drive train and power on the diagram.

3. What element in the drive train causes the biggest propulsive losses? ________________

4. From the data for a displacement of 172 LT, and assuming a propulsive coefficient of 55%, determine the shaft horsepower required to propel the YP at its maximum speed of 13.25 knots.

5. YP's are equipped with two propeller shafts with one 437 HP diesel engine driving each shaft. Why would two engines be used instead of a single 875 HP engine driving a single propeller shaft?

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Shown below is a plot representing the SHP and fuel consumption a single propulsion engine. Use this plot to answer the remaining questions in this lab.

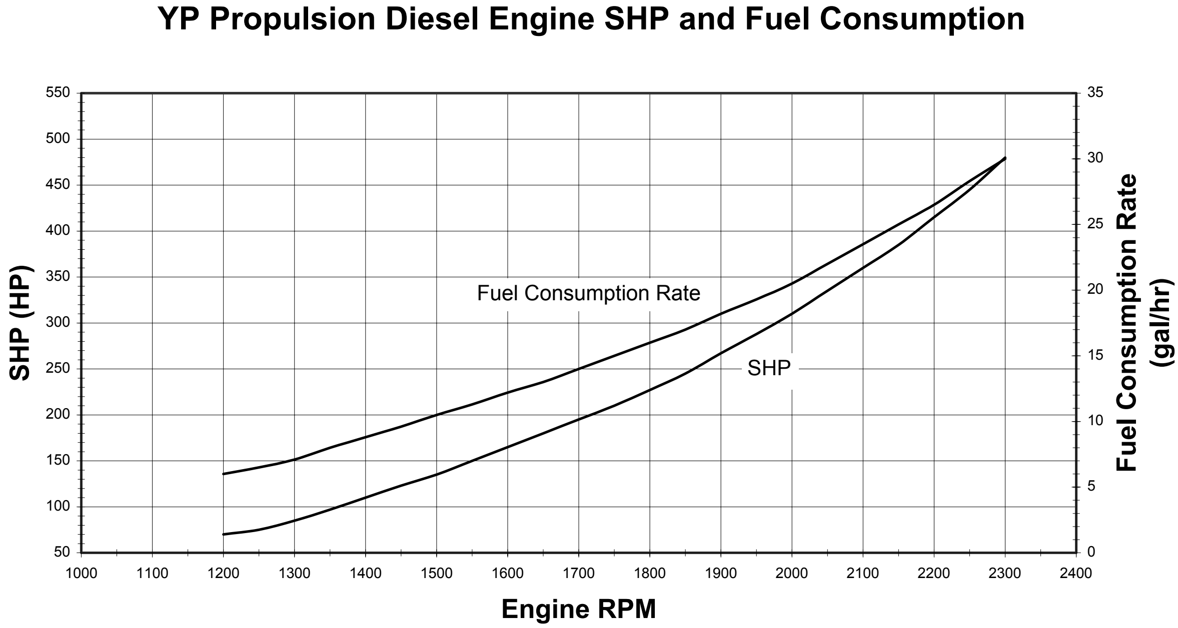

Figure 3: Shaft horsepower and fuel consumption data for a single YP diesel engine

6. From the experimental EHP data and assuming a propulsive coefficient of 55%, determine the total SHP required to travel in calm water at 10 and 12 knots for both displacements. Then calculate the shaft horsepower required from each engine to meet the total SHP requirement. Place your results in Table 5 below.

Table 5: YP Fuel Consumption Table

Δ (LT)	V_S (kt)	Total EHP (from plot)	Total SHP	SHP per Engine	Fuel Consumption Rate per Engine (gal/hr)	Total Fuel Consumption Rate (gal/hr)
139	10					
139	12					
172	10					
172	12					

7. Using the fuel consumption curve on the previous page, determine the fuel consumption rate for each engine at each SHP. To do this you will need to enter the curve using the value of SHP, then determine the engine rpm corresponding to that value of SHP. Finally, using the engine rpm value, determine the fuel consumption rate at that rpm.

8. Calculate the total fuel consumption rate for the YP at each speed and displacement and enter that value in Table 5.

9. How has the increase in displacement affected the amount of fuel burned by the YP?

____

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10. When fully loaded, a YP carries 6,800 gallons of fuel. Using data for a displacement of 172 LT, how many hours can a YP steam, and how many nautical miles can it travel before it completely burns all of its fuel? Use the space below for your calculations. Enter your results in the table below.

Table 6: Steaming Distance and Steaming Hours at Δ_S = 172 LT		
V_S (kt)	**Maximum Steaming Hours**	**Maximum Distance (NM)**
10		
12		

11. How would wind and current affect the YP's fuel consumption?

12. Shown below is a table of engine rpm and a corresponding ship speed. Using this table and the fuel consumption chart, answer the following question. It is desired to travel a distance of 1800 nautical miles and arrive with 50% fuel onboard. What speed must the YP travel at in order to meet this requirement?

YP Engine RPM Table	
Engine rpm	**Speed (kts)**
500	4
825	6
970	7
1125	8
1290	9
1460	10
1650	11
1850	12
2060	13
2100	13.25

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YP EFFECTIVE HORSEPOWER vs SPEED